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INTERFACES FOR PLANNING VEHICLE ROUTES

Government Interest

This invention was made with Government support under Cooperative Agreement No. NCC-1-291 awarded by NASA Langley Research Center. The Government may have certain rights in the invention.

Technical Field

The present invention relates to vehicle navigation, and more particularly concerns the planning of aircraft routes, including display and user interaction.

Background

The aviation community has a goal of reducing the fatal-accident rate by eighty percent within the next ten years. At the same time, air traffic continues to increase, and the national airspace system is undergoing major changes. In particular, it is likely that aircraft pilots will be given more responsibility for avoiding hazards themselves.

Weather is a factor in a third of aircraft accidents. The National Aeronautics and Space Administration (NASA) is presently embarked upon a multi-year effort to provide better weather information and to improve hazard characterization, condition monitoring, data display, and decision support. At the present time, controllers, dispatchers, and air-traffic managers have access to a number of weather-information products from private vendors and from government services. Graphic displays of weather information on large airliners are limited to onboard weather radars and information from paper weather briefings. En-route updates are delivered either as voice messages via radio or as alphanumeric data-link printouts onboard the aircraft.

Flight planning is a complex task. A strategic planning and replanning tool produces a flight plan that describes the track, speed, and altitude that an aircraft will fly during various phases of an entire flight. Because the underlying models and assumptions made in a completely automated system may be incomplete or fallible, some have suggested the broad concept of a cooperative planner that interacts with a human operator. Pilots and dispatchers alike have stated that merely providing additional hazard information would not adequately support effective decision-making for routing choices.

A need therefore remains for more advanced facilities for generating and modifying route plans for aircraft, both for increased safety and for better ease of use.

Summary of the Invention

The present invention offers systems and methods for producing routes for aircraft and similar vehicles in response to a number of factors, including weather hazards and other in-flight conditions.

The invention offers systems and methods for interactive route planning in the face of weather and other hazards. It also furnishes data representations and models for factors that influence route planning, such as arrival time, fuel efficiency, passenger comfort, overflight fees, and conditions at terminals, including traffic congestion and closure of runways and other facilities. It further supplies an interface for facilitating the display of in-flight condition data and the manipulation of the route. It can optionally be used with a route optimizer for modifying computer-generated proposed routes.

The invention achieves these and other objectives by displaying hazards of different types in response to received data and defining boundaries and/or other specifications characterizing the hazards for purposes of the flight plan. Controls permit a user to modify the displayed data and to manipulate the route.

Drawing

Fig. 1 is a high-level block diagram of a system according to the invention.

Fig. 2 is a schematic diagram showing data representations used in the invention.

Fig. 3 is a high-level flowchart showing the operation of the system of Fig. 1.

Fig. 4 is a diagram of a computer display for the system of Fig. 1.

Fig. 5 shows a properties box for the display of Fig. 4.

Detailed Description

This description and the accompanying drawing illustrate specific embodiments in which the present invention can be practiced, in enough detail to allow those skilled in the art to understand and practice the invention. Other embodiments, including logical, electrical, and mechanical variations, are within the skill of the art. Other advantages and features of the invention not explicitly described will also appear to those in the art. The scope of the invention is to be defined only by the appended claims, and not by the specific embodiments described below.

Fig. 1 is a high-level block diagram of a system 100 for manipulating flight-plan information according to the invention. Block 110 is a structure for data representing a

flight plan or intended route. Block 120 contains data representing one or more hazards associated with the flight plan. Computer program code 130 implements an interface for entering data into and displaying the data from blocks 110 and 120. Route source 140 can be an optimizer containing computer program code for automatically generating flight plans to minimize a cost function that includes fuel, flight length, and/or other factors in the presence of hazards or other constraints. U.S. patent application Ser. No. 09/312632, "Hazard Detection for Flight Plans and the Like," by Stephen G. Pratt and Gary L. Hartmann (attorney docket H16-25458), hereby incorporated by reference, describes an example of such an optimizer. More generally, block 140 can be considered to be any source of flight plans, including standardized plan templates and plans entered manually in interface 130 by a user. Blocks 110-140 can form a part of a computer of any convenient type, general-purpose or special-purpose, such as the personal computer shown at 150, having devices 151-153 for entering and displaying data. Some or all of the data may come from an external source such as a weather service, and is input to computer 150 via a communications device 153. Code for implementing any of the functions of computer 150 may be represented on a medium such as signals from device 153 and/or stored on a medium such as a disk 154 external or internal to computer 150.

Fig. 2 is a schematic of a geographical area 200 illustrating data used in system 100. Flight plan 210 is represented as a sequence of segments 211-213 between preselected waypoints 214-217. The waypoints have both horizontal and vertical parameters; each is defined by a latitude, a longitude, and an altitude. The flight plan can be created by an operations center, a dispatcher, or a pilot, or by a computer program such as optimizer 140.

'Hazard' is a general term for any feature or condition to be avoided by the flight plan. Many of the significant hazards concern weather, e.g., convection, turbulence, and icing. Other atmospheric conditions include volcanic ash and stratospheric ozone concentrations. Political designations such as military training areas and areas having overflight fees or restrictions can also be considered to be hazards. Any condition that can be represented to system 100 can in fact be a hazard in the present context. Hazard data can come from any number of sources, including fixed-base and on-board weather radar, private and governmental operations, and aviation charts. The present system also permits a system operator to enter hazard data and types directly via interface 130..

Hazards are instantiated as polygons such as 220. Polygons have compact representations in terms of vertex points or edge lines. They can be easily transformed to represent movement; and they can be generalized easily to three dimensions. A hazard polygon is defined in terms of the latitudes and longitudes of its vertices 221-225. The

edges are great-circle connections between adjacent pairs of vertices. The number of edges is arbitrary. If desired, hazards can also be represented by polytopes (not shown) in three dimensions; the vertices then have altitude parameters as well. Hazard motion can be represented by a vector 226 that specifies the direction and velocity of the polygon's centroid. Additional vectors such as 226' can be added in a sequence to define a path over a certain time interval. This embodiment simplifies calculations by requiring that all polygons be convex. However, more complicated shapes such as 230 can be constructed from multiple convex polygons 231, 232, etc. Each weather region or polygon also has an associated set of property data that includes the degree of its danger, such as severity, coverage, and forecast probability.

Because illustrative system 100 is a strategic planner that operates over an entire flight plan, the grid size 201 for representing features within area 200 varies with the length of the flight. In the interest of reducing calculations to a reasonable number, this embodiment is not constructed to thread its way through, say, one-km diameter convective cells on a coast-to-coast flight of 5000km. Improvements in computing speed might, however, eventually allow the avoidance of individual small hazards, and even the integration of tactical aspects into the same system. The strategic nature of the system also results in prioritizing hazards that occur in the cruise phase of a flight. For example, although microbursts affect aircraft performance significantly, their effects usually occur at lower altitudes, in the take-off and landing phases, and they receive a lower level of attention in this implementation.

Some hazards, especially weather hazards, come in varying intensities. Rather than adding this complication to the process, this implementation considers only hazards that the operator considers dangerous, and permits the operator to set thresholds for different hazards, so that only those above the thresholds are displayed for consideration. This simplifies the data display for the user, allows more concrete control over an optimizer such as 140 through direct manipulation of the hazard boundaries, and permits clear visualization of routing decisions made by an optimizer. Moreover, sharp visible boundaries around hazards allow application of the same standards to multiple flights, and permit a user such as a dispatcher to better understand the effects of a (human or computer) routing decision for one flight on the operation of a fleet as a whole.

Fig. 3 shows the overall cycle 300 of system 100, Fig. 1. Block 310 acquires hazard data from an outside source such as those mentioned above. Block 320 acquires information from a user who manipulates interface 130 to create and delete hazard zones and types and to set thresholds for various types of hazard. Different flight conditions can be treated differently. For example, a cargo flight might elect to fly through a

turbulent area that an airliner might wish to avoid in the interest of passenger comfort. Also, a pilot might decide to fly through an area of scattered convective activity and make small-scale lateral deviations to avoid isolated cells. On the other hand, an area of dense activity would be circumnavigated as a whole. There are common terms that can be employed for thresholding. For instance, 'isolated' activity refers to single cells, 'widely scattered' to activity occurring in 25% or less of an area, 'scattered' to up to 54%, and 'numerous' to 55% and more. Terms of probability are also in general use, such as 'slight chance' for 10-20% probability of precipitation, 'chance' for 30-50%, and 'occasional' for an activity that has at least 50% probability, but over less than half of the forecast period. These terms are not necessarily consistent among different conditions; e.g., 'occasional' turbulence occurs less than $\frac{1}{3}$ of the time, while 'intermittent' occurs up to $\frac{2}{3}$, and 'continuous' occurs above that amount. Some conditions are governed by airline policy, such as restricting passenger flights to altitudes below ozone concentrations above a toxic level. Other conditions, such as icing, are mandated for avoidance above certain levels. In addition, different icing restrictions apply to different aircraft; the present invention allows a dispatcher to set different restrictions such as icing on an aircraft-by-aircraft basis.

Block 330 generates the boundaries of hazard polygons such as areas 220 and 230, Fig. 2, from the information provided by blocks 310 and 320. Again, restricting the boundaries to convex polygons (or polytopes) simplifies calculations for the optimizer, but is not a requirement for the concept. Block 340 receives data representing a route. As noted above, routes can come from many different sources: an optimizer such as 140, a stored library of plans, or directly from a user input through interface 130. Block 350 displays the hazard areas and the computed flight plan via interface 130. Block 360 then iterates the cycle if the user so desires. Block 370 outputs information 110, Fig. 1, concerning the flight plan.

Fig. 4 shows a computer display 400 for interface 130, Fig. 1. Area 401 contains lateral schematic representations of route data 110, hazard data 120 on a background of geographical and other data useful for context. Area 402 is a representation of the route and hazard data in a vertical slice through the route. Area 403 contains representations of standard control icons for manipulating data representations in area 401. Display 400 integrates human factors and human-centered design strategies for ease of operation. The design of this embodiment uses current conventions adopted in the aircraft industry in order to maintain uniformity where feasible, but is not limited to those conventions where they do not serve the functionality of the present system. The overall display follows the "dark cockpit" philosophy that advocates subdued colors for normal operation, in order to

reduce eyestrain and increase readability across a range of environmental conditions. Black is employed as a background color for the displayed elements, as is almost universal in aviation instrumentation. (Fig. 4 uses colors better adapted to clarity of exposition.)

Area 401 includes a map-like plan or lateral depiction of the geographic area of the flight, in this example, from Tokyo Narita (TKO) airport to Minneapolis-St. Paul Lindbergh (MSP) airport. For large geographic areas, the lateral depiction follows a modified conical projection, as employed by World Aeronautical Charts (WAC).

A proposed flight-plan route 410 has segments between a number of waypoints, shown respectively as heavy lines and small filled circles in Fig. 4. The data display does not directly show the altitudes of the waypoints in this view. Symbol 411 shows the aircraft position at the current time index. Multiple routes (not shown) can be displayed simultaneously, if desired, by using characteristics such as stippling to differentiate them from each other. A user can manipulate flight plan 410 by inserting mandatory or constrained waypoints, and by moving or deleting waypoints. Conventional clicking and dragging operations with a data-entry device 151 such as a mouse can realize such functions. The term "mouse" should be taken broadly to include any kind of cursor-positioning device, such as a trackball, joystick, etc.

Regions indicated collectively as 420 display the various types of hazards or other conditions to be avoided. The boundaries of hazards are shown by irregular lines. In the actual display, various types of hazards are shown in different colors or hues that are shaded to indicate severity. Specific colors and shades are selected to enhance visibility in the specific environment. For example, lighter shades indicate higher severity levels in display 400 in order to enhance contrast with the choice of a dark background. Also, because weather phenomena tend to occur in the same vicinity, hazard areas frequently cluster on the display. The drawing order of hazard regions therefore follow an assigned order of importance: volcanic activity highest, then level-3 convective activity, level-3 icing, level-4 turbulence, and level-2 ozone lowest. Color transparency (i.e., alpha axis) also facilitates the perception of multiple elements such as weather and land that might occur in the same location. Also, as described below, the operator can filter various phenomena to view only those of current interest. Display 400 includes all severity levels of the hazards, although some levels could be filtered out if desired. Fig. 4 depicts three illustrative kinds of hazard with different patterns on their boundary lines to symbolize the different colors: solid lines indicate convective weather, as at 421-423; dashed lines 424-426 are icing; and dot-dash lines 427-429 are turbulence. The boxed numerals associated with each region indicate the severity and/or probability of the hazard. A

visual effect such as varying amounts of stippling could be used as at 427' to indicate greater or lesser areas of coverage of a hazard within the defined boundary.

Polygons or other boundaries 430 enclose hazard regions 420. An operator draws individual polygons 431-439 by selecting and dragging points with a mouse or other input device. Hazard polygons can also be drawn by operators other than the one constructing the flight plan, and can be automatically generated by a source that provides hazard information to system 100. Such hazards can also include properties in files that produce properties boxes. Some or all of this information can be included as default or nominal values.

A direction and/or rate of travel can be imparted to the polygon by selecting the center of the polygon and dragging a vector. A path of multiple successive vectors can also be entered. A single polygon can enclose multiple weather regions; polygon 432, for example encapsulates a squall line having multiple cells that are considered so closely spaced as to prohibit penetration of the entire region. Hazards other than those built into the system can be defined and entered as a "custom" type.

The operator can open a properties box for a polygon by double-clicking the polygon. Fig. 5 shows an example 500 of such a properties box. The operator can enter information associated with the hazard, including a name, a severity level, a description, times during which the hazard is valid, vertical dimensions, and notes. For moving hazards, the properties can include:

- An initial time value, at which the drawn vertices represent the position of the hazard. Typically this time value is in the future, and the vertex points incorporate weather-model or other forecast information.
- The position of a point that represents the center of motion of the hazard polygon.
- The heading and speed of the polygon's motion at the center position. The motion occurs along a great circle rather than along a rhumb line, so the direction changes over large distances.

Because hazard polygons move along great-circle paths, the display program transforms its coordinates from earth frame into a reference frame that coincides with the great circle, rotates it at an angle corresponding to the distance traveled at its specified speed, then transforms the coordinates back to the original earth frame for presentation in area 401. This embodiment employs a constant shape for moving hazard polygons. However, it is possible to define multiple shapes for different times if desired. It is also possible to vary course, speed, and other properties over time if the added complexity is worthwhile.

Area 401 can also show geographic, topographical, political, and other features. Partial lines 441 and 442, for example, indicate coastlines for landmasses rendered in subdued transparent colors.

Area 401 can also include some data and control icons 450. Legend 451 shows the date and time of the flight. Movie-player control 452 of a conventional type indicates the current time index for depicting the positions of hazard shapes 420 and 430, and of aircraft symbol 411. The associated slider varies the time index under operator control, and the flight plan can be played through time with the conventional recorder-type buttons, thus animating the moving hazards and aircraft symbol. The buttons select continuous play, pause, beginning, and end. Control 453 shows and modifies the altitude of the horizontal slice of airspace being shown in area 401; full slider displacement shows all altitudes.

Floating window 454 contains controls and color/shading conventions for the various types of hazards. The text labels name the hazard types, and include an operator-defined 'custom' type. The bars represent the hue used to designate each type of hazard in regions 420 and polygons 430, and the shadings used to indicate different severity levels of each hazard. (For clarity, color designations have been omitted from the regions and polygons in Fig. 4.) The check-boxes in window 454 permit an operator to select whether hazards of the corresponding type are to be displayed or not.

Area 402 is a vertical depiction of the route, taken through a slice along the segments of flight plan 410', and includes the waypoints and aircraft position indicator 411'. The vertical scale is exaggerated greatly over the horizontal scale. Light horizontal lines 460 denote altitude increments above mean sea level, marked in flight levels (i.e., hundreds of feet). The level of dashed line 461 is set by the altitude slider of control 453. The vertical projections of hazard areas 421', 425', and 428' and their polygons 431', 435', and 438' that intersect route 410' are shown in area 402.

Area 403 contains data values and control structures that affect the flight plan. General information identifying the flight and a route iteration number are contained in general-information cluster 470. The operator can select a flight, and select among several alternative routes with drop-down combination boxes. This subarea also includes information concerning the origin, destination and waypoints. A scrollbox contains information relating to waypoints, such as their names ("wpt3," etc.), bearings, estimated times en route, and remaining fuel. The user can enter required times of arrival (RTA), altitudes, and other constraints here as well. Threshold cluster 480 includes sliders for permitting an operator to set threshold severity values for a number of different types of hazard, such as convective weather ("Con"), icing ("Ice"), ozone concentrations ("Ozn"),

turbulence ("Trb"), volcanic ash ("Ash") and custom zone ("Cz"). Recommended maximum values appear in boxes above their respective sliders. A user drags the sliders to set threshold values that the user wishes the flight plan to avoid. These values can be communicated to optimizer 140.

Subarea 490 contains information regarding one of the hazard regions 421-429, in response to a single mouse click over its corresponding polygon 431-439. Fig. 4 shows the information for region 426, named "Icing Bravo" in the top entry of subarea 490. Other entries show a severity level and an estimated time of intercept with the flight path, the location of the center of the hazard polygon, the range of severity levels found within the hazard region, a time block during which the hazard exists, and the severity trend of the hazard. Users can enter time-stamped notes at the bottom of the subarea. Some of the other entries can also be edited by direct entry of data, although some are prohibited and others are constrained to certain data values. In the latter case, clicking and holding on the text field of an entry elicits a drop-down menu of possible values for that entry. Clicking and holding on the "Hazard" entry produces a drop-down of the names of all the displayed hazards, plus a "New Hazard" choice for adding a hazard to the display. Selecting any of the choices in the "Hazard" drop-down list also generates a properties box 500 for that hazard in area 401.

Conclusion

The invention presents systems and methods for displaying and manipulating routes for aircraft and other objects in the presence of hazards. Many variations and generalizations within the scope of the invention will occur to those skilled in the art. In particular, the term "flight plan" must be taken broadly to include routes for other vehicles, and similar plans for maneuvering in the presence of hazards. Likewise, hazards are broadly defined as conditions that might affect the plan of the route. Hazards can, for example include political and other zones in addition to weather and similar phenomena. This term can include regions that might be more desirable than surrounding regions (i.e., have a negative cost), rather than only regions that should be avoided entirely. Some hazards can be other than regions having a geographic extent or physical boundaries; for example, some intermediate stops might impose landing fees that increase the overall cost of a flight. Hazard boundaries or other designations can be indicated other than by polygons or other linear structures. Multiple nested polygons could represent different costs associated with different levels of a hazard region. The division of the described systems and methods into blocks in the above description does not imply that other divisions are not possible or desirable. Indications that some components or

steps are convenient or preferred does not imply that others might not be desirable or within the scope of the claims. The sequence of blocks in the description and of recitations in the claims does not imply any particular time order.

We claim as our invention: